Project Title: Collaborative Research: CPT for Improving the Representation of the Stratocumulus to Cumulus Transition in Climate Models

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First Year Progress Report: From 09/2010 to 06/2011

Results and Accomplishments

The strategy for this CPT is to make progress in representing the stratocumulus to cumulus (Sc-Cu) transition in the NCAR and NCEP global models by diagnosing and improving process interactions, in particular analyzing the LES and SCM simulation of two new Sc-Cu transition GEWEX Cloud System Studies (GCSS) cases.

In this context, the results and accomplishments of this first year can be divided in:

1. Global diagnostics of the NCAR and NCEP models;
2. Large-Eddy Simulations of Sc-Cu transition cases;
3. Single-Column Model (SCM) simulations of Sc-Cu GCSS transition cases;
4. Development and implementation of new parameterizations.

1. Global diagnostics of the NCAR and NCEP global models

The UCLA team (in collaboration with NCEP and NCAR) produced general diagnostics of the climatology simulated by the NCAR CESM 1.0 (coupled version of CAM 5.0, 200-year run) and by the NCEP CFS (coupled version of the current NCEP GFSdev, 20-year long and ongoing). As an initial step the NCAR AMWG diagnostic package was modified to include the capabilities to process NCEP output. These general diagnostic studies led to the important finding that the NCEP CFS has a TOA energy imbalance (excessive warming) of ~ 9 W/m^2. The cause of this imbalance is currently under investigation. In general, both models reproduce reasonably well the basic global circulation patterns (with the NCAR CESM 1.0 showing slightly stronger "double-ITCZ" bias in the precipitation pattern). Both models have obvious biases in the cloud fields and associated radiative forcings.

Next, the work focused on the simulation of the climatological Sc-Cu transition in the subtropical eastern oceans. Figure 1 compares the October climatologies of low cloud fraction and cloud water path in the Pacific from the models and observations. Both models have biases in terms of low clouds in the subtropical eastern Pacific: the NCAR CESM produces reasonable low cloud amount and LWP near the coast but suffers from a sharp drop-off in cloud fraction and LWP about 20 degrees west off the coast in the subtropics; the NCEP CFS produces little stratocumulus off the Californian coast and the Peruvian and Chilean coast and produces excessively persistent low clouds almost all the way to the SPCZ.
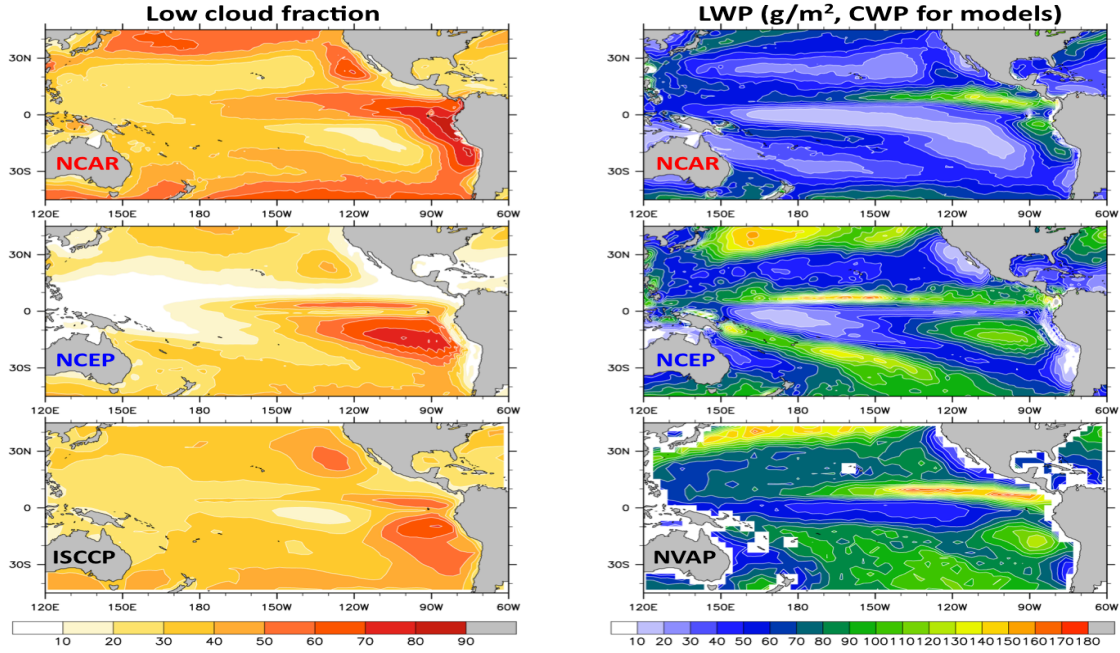
Figure 1: The left panel shows October mean low cloud fraction (%) from the NCAR CESM 1.0 (upper), the NCEP CFS (middle) and ISCCP observation (lower). The right panel shows October mean cloud water path (liquid and ice, g/m²) from the NCAR CESM 1.0 (upper), the NCEP CFS (middle) and satellite observed Liquid water path from NVAP.
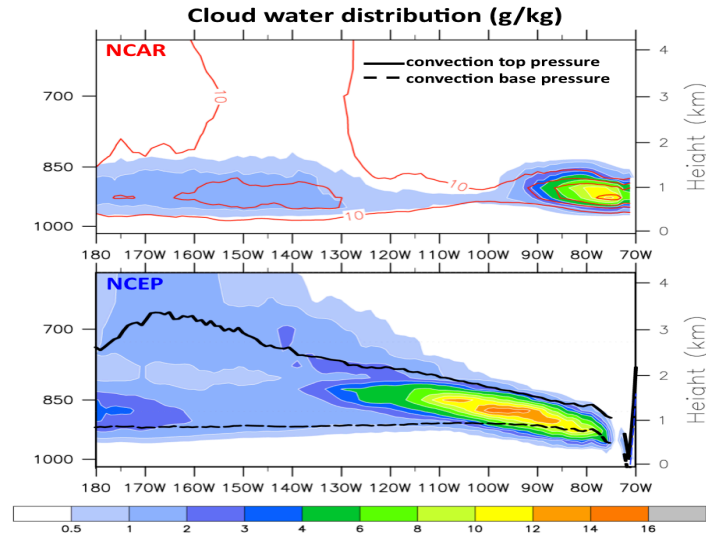
Figure 2: Vertical distribution of cloud water (10^{-2} g/kg) along 20°S in October in the Southeastern Pacific from the NCAR CESM (upper) and the NCEP CFS (lower). Red contours show the cloud fraction in the upper panel. The black solid and dash lines denote the convective top and base levels respectively in the lower panel.

More detailed diagnosis was performed to link the biases in the simulation of low clouds with the PBL and cumulus parameterizations in the two models. Figure 2 shows the

October mean vertical distribution of cloud water along 20°S in the Southeastern Pacific in the two models.

In the NCAR simulation (upper panel), a layer of low-lying (slightly below 1km) stratocumulus is present between the coast (at ~70°W) and 90°W but drops off to almost nothing to the west. The drop-off of cloud coincides with the intensification of shallow convection. This leads to the speculation that intensified shallow convection west of 90°W leads to the accelerated break-up and destruction of the stratocumulus layer.

In the NCEP CFS simulation (lower panel), a layer of stratocumulus exists to the west of 75°W. Towards the east end of this stratocumulus layer, the cloud water is mainly supplied by condensation at the PBL top. More to the west, this stratocumulus layer is partly generated by the detraining shallow cumulus mass flux and thus co-evolves with a cumulus cloud layer, which deepens towards the west. In stark contrast to the situation in the NCAR, co-evolving stratocumulus and shallow cumulus layers in the NCEP CFS lead to excessive low cloud cover as we have seen in Figure 1.

2. Large-Eddy Simulations (LES) of Sc-Cu transition cases

The UW team has used the SAM LES model to simulate the GCSS composite Sc-Cu transition case, which is based on a slight idealization of a composite Lagrangian evolution of cloud topped boundary layers over the NE Pacific during a 3-day period during which they advect over warmer water, rapidly deepen and transition from solid stratocumulus cloud to a broken, cumulus-coupled cloud field. These simulations, shown in the bottom part of Fig. 3, are part of a GCSS intercomparison study led by Irina Sandu of ECMWF. The UW team have also performed an LES sensitivity study with cloud droplet concentration reduced fourfold for future comparison with the NCAR SCM.

The JPL/Caltech team has used a recently developed (at JPL/Caltech) LES model based on the original UCLA LES with modifications to the subgrid closure and the numerics to simulate the GCSS Sc-Cu transition case as well. In addition the JPL team simulated a variety of steady-state Sc and Cu cases to analyze in more details the steady-state statistics of these cases.

3. Single-Column Model (SCM) simulations of Sc-Cu GCSS transition cases

The UW team ported the NCEP GFS SCM to the UW Linux cluster and has modified it to run several of the key GCSS boundary layer cloud intercomparison cases, including a dry convective boundary layer (DCBL), BOMEX (shallow cumulus), DYCOMS (nocturnal stratocumulus), and the ongoing GCSS Sc-Cu transition case. This involved significant unanticipated coding effort, because the GFS and its SCM were not written and documented for this kind of use. The DCBL case suggests that the NCEP boundary layer scheme maintains too deep a super-adiabatic layer near the surface, but performs fairly well overall in cloud-free convective conditions.

The BOMEX case run with the old and new shallow cumulus parameterizations was compared with the LES. The new parameterization produces too little cloud, much less than the old parameterization. This bias may be due to interaction between the cumulus parameterization and the grid-scale condensation/microphysics schemes via detrainment,

rather than internal details of the cumulus parameterization itself. It also tends to excessively deepen and dry the shallow cumulus layer compared to LES. The NCEP SCM simulation of the GCSS transition case is shown at the top of fig. 3. It gives encouraging agreement in vertical structure and liquid water path to the LES.

The NCAR team showed that SCAM5 simulates the case fairly well at its default 30-level vertical resolution, but produces too little cloud at 80-level resolution, and showed that better results could be obtained by modifying the UW moist turbulence and shallow cumulus parameterizations into a single unified approach (UNICON) – see below.
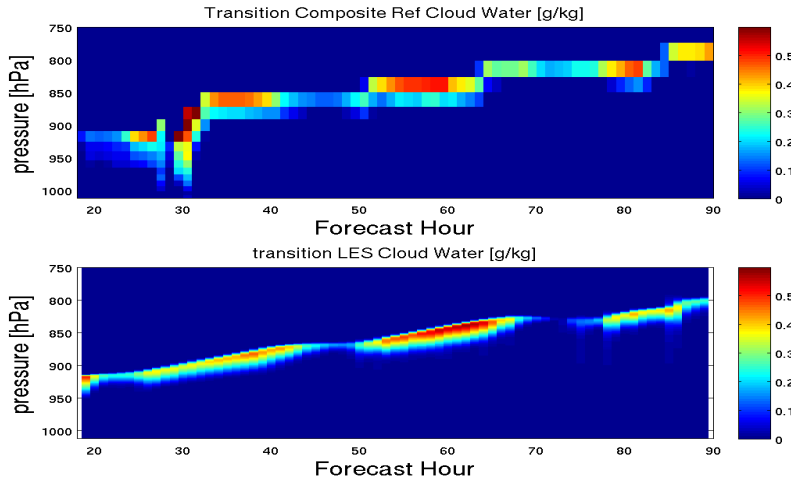
Figure 3. Simulations of the GCSS composite Sc-Cu transition case with the SCM version of the NCEP GFS model (top) and the SAM LES model (bottom).

4. Development and implementation of new parameterizations

The LLNL team (in collaboration with NCAR and UW) has implemented a PDF-based cloud macrophysics in NCAR's CAM5. Several test simulations showed promising results with more mid-level and high-level cloud fractions than the current prognostic macrophysics.

The NCAR team (in collaboration with UW) has been developing UNICON, and has tested UNICON in the GCSS Sc-Cu transition. Compared to CAM5, UNICON clearly reduced the biases of temperature and moisture in the cloud and sub-cloud layers. It also turns out that UNICON simulates more reasonable column-integrated cloud LWC and cloud fraction than CAM5.

The sedimentation-entrainment feedback is one of the important missing processes in CAM5 necessary for simulating aerosol-cloud-climate feedback. The NCAR and UW teams have implemented and tested sedimentation-entrainment feedbacks in CAM5 and found that its impact on the global aerosol indirect effect is smaller than the speculated magnitude.

The JPL/Caltech team is implementing and testing the Eddy-Diffusivity/Mass-Flux (EDMF) mixing parameterization in the SCM version of the NCEP GFS model.

Highlights of Accomplishments

- Adapting the NCAR AMWG diagnostics package to analyze 20-year simulations with NCEP CFS – highlighting an NCEP TOA energy imbalance;
- Specific diagnosis of the Sc-Cu transition in the subtropical Pacific simulated by the NCEP CFS and NCAR CESM;
- SCM simulations with NCEP and NCAR models of GCSS cases including Sc-Cu transition – note that this is the first time that NCEP participates in GCSS;
- LES simulations of the GCSS composite Sc-Cu transition and submission of results to the GCSS case organizers;
- LES simulations of a variety of Sc, Cu and Cu under Sc steady-state case-studies;
- Implementation and evaluation of new parameterizations in the NCAR model: PDF-based cloud macrophysics an unified convection UNICON;
- Implementation and evaluation of EDMF parameterization in NCEP model.

Publications from the Project

Several publications are currently in preparation.

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Budget for Coming Year

	Year 2 (in $)
U. Washington	191,061
NCAR	93,181
UCLA	119,275
JPL	123,742

Future Work

- Investigate current NCAR and NCEP climate simulation biases (e.g. NCEP TOA imbalance) and the impact of biases in the simulated Sc-Cu transition;
- Analyze in detail the statistics of the LES Sc-Cu transition simulations;
- Analyze in detail the NCEP and NCAR SCM simulations of GCSS Sc-Cu cases;
- Perform a detailed evaluation of the new PDF-based cloud macrophysics and mixing scheme UNICON, and interactions with other schemes in NCAR model;
- Perform a detailed evaluation of PDF-based cloud and EDMF parameterizations, and interactions with other schemes in the NCEP model.